

# COMBAT HYBRID EVOLUTIONIZING POWER AND

MAJ Edwin W. Leathers Jr., Eugene Danielson, George Frazier and Byron Wong

The CHPS program succeeded in demonstrating the integration of essential power elements. Here, SSG Thomas McKean, with Headquarters-Headquarters Company, 2nd Battalion, 63rd Armor Regiment, provides security from the hatch of an M113 APC, Sept. 11, 2004. (U.S. Army photo by SPC James B. Smith Jr., 55th Signal (Sig.) Co. (Combat Camera).)

**T**he Combat Hybrid Power System (CHPS) stemmed from an initial government research and development (R&D) effort focused on integrating hybrid electric component technologies toward a specific vehicle platform and application. This program's Phase I began in 1996 as a joint initiative between the Army and the Defense Advanced Research Projects Agency (DARPA). This first slice consisted of formulating basic capabilities, characteristics and requirements for a notional manned ground vehicle (MGV). Numerous design and concept candidates were analyzed and were considered for further investigation. Based on these CHPS program candidates, a series architecture configuration was selected to be constructed and commissioned during the next stage.

# POWER SYSTEM — ENERGY DEVELOPMENT

The CHPS' goal was to demonstrate alternative vehicle power strategies with hybrid electric (HE) power architectures and power management strategies in a combination of real and virtual environments. The emerging Army vision of future land warfare places strong emphasis on technology supporting early entry of light, modular, efficient land forces. Future vehicles will be required to demonstrate significant increases in mobility, survivability and lethality while reducing logistics burdens.

The CHPS program demonstrated total integration of the essential power components and technologies that

enable these enhanced capabilities, which are important aspects of an early-entry capability. Military vehicles developed using the HE power architectures can be more fuel efficient than those with conventional drive trains. Total system weight will also be reduced by employing hybrid system vehicle designs that take advantage of smaller high-temperature power electronics components, centralized all-vehicle

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power distribution, component placement flexibility and advanced weapons/protection systems that are not plausible with mechanical systems. HE power is an essential enabling technology for future combat vehicles, given the number of electrically powered subsystems planned for implementation in the Future Combat Systems (FCS) fleet.

Continuing as a DARPA-managed program with



The BFV benefited from early CHPS development. Soldiers from Bravo Co., 2nd Battalion, 2nd Infantry Regiment, 1st Infantry Division (1ID), pull security along a road in Mosul, Iraq, Jan. 8, 2005. (U.S. Army photo by SPC Adam Sanders, 55th Sig. Co. (Combat Camera).)

focuses emerging from the hardware and software tools from Phase I, CHPS moved forward with three primary objectives:

- Develop a Systems Integration Laboratory (SIL).
- Develop virtual prototyping.
- Develop critical enabling component technologies.

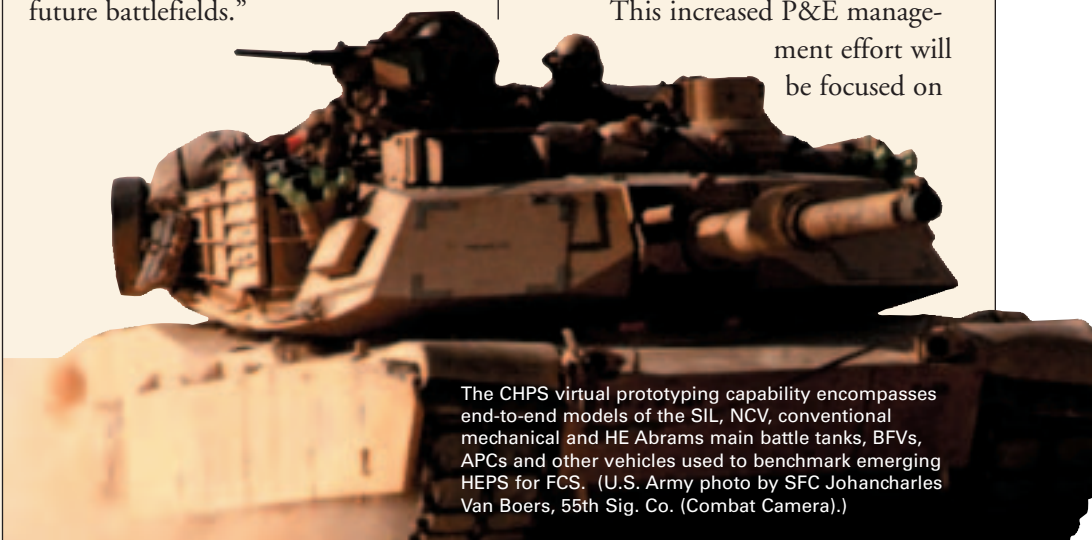
The basic objectives were to have an operating SIL and virtual prototyping capable of providing data critical to the characterization and validation of the hybrid power architecture with advanced components.

In 2000, CHPS transitioned from DARPA to the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC), headquartered at the Detroit Arsenal in Warren, MI. CHPS was an Army Science and Technology Objective in 1999 with plans to continue through 2005. However, because of an emphasis to support the FCS Milestone B decision in 2003,

TARDEC accelerated the CHPS program to conclude by the end of FY03. The CHPS program succeeded in demonstrating the integration of essential power components representative of FCS MGVs. According to TARDEC's Power and Energy business manager, "The technologies being developed under the Army's CHPS program will continue to be increasingly crucial to fighting and winning future conflicts, with our goals of reduced logistics burden on complex, high-power-demand future battlefields."

The FCS Milestone B decision in 2003 led to a new baseline for the MGVS variants and was issued in the FCS program's system development and demonstration phase. The baseline decision confirmed the original CHPS premise that the best propulsion choice for the MGVS (18- to 20-ton range) was a series hybrid electric power system (HEPS). With the new Increment I FCS baseline established, TARDEC shifted the emphasis to future power and energy (P&E) technologies that can support FCS spirals.

This increased P&E management effort will be focused on



The CHPS virtual prototyping capability encompasses end-to-end models of the SIL, NCV, conventional mechanical and HE Abrams main battle tanks, BFVs, APCs and other vehicles used to benchmark emerging HEPS for FCS. (U.S. Army photo by SFC Johancharles Van Boers, 55th Sig. Co. (Combat Camera).)

the vehicle system level and will also be developed with an interconnected link to battlefield system-of-systems integration. Future articles will describe progress made in the P&E hardware-in-the-loop SIL program that superseded CHPS.

## Military HE Power Issues

CHPS was the Army's main R&D program that addressed pulsed power requirements as part of a combat HEPS — a system in which pulsed power and continuous power must operate together without interference. Continuous power is necessary to propel the electro-magnetic vehicle, to provide hotel loads and to act as an auxiliary power unit for other electrical loads. In fact, developing CHPSs is much different from developing passenger cars, transit buses or other civilian vehicle hybrid systems. The main influences in civilian vehicle designs are fuel economy, emission control and cost. Keeping these parameters in mind, military vehicle designers must also consider deployability, agility, versatility, lethality, survivability and sustainability.

Consequently, power system architectures typically differ significantly between the two applications. Existing and planned civilian vehicles generally use parallel hybrid technology to minimize power excursions in the prime power system.

Leading military systems under current study primarily use a series hybrid topology to enable higher powers and the need to supply multipurpose loads. For instance, pulsed power for advanced electric weapons and survivability systems is a unique military requirement anticipated for FCS. A classic civilian vehicle would not have this pulsed

power requirement. Figure 1 provides the performance comparisons between commercial and military vehicles.

	Commercial Vehicle	Military Vehicle
Fuel Economy	EPA Standard	30%-50% Improvement
Fuel Type	Gasoline	JP-8 or Diesel
Hybrid Architecture	Parallel	Probable Series
Power Density	3.0 Wheel HP/ft <sup>2</sup>	>5.6 Req'd, 8.0 Desired
Armor	No	Yes
Silent Watch	No	Yes
Silent Mobility	No	Yes
Electrical Energy Storage	<2kW-Hr	30-40 kW-Hr
Grade	<45%	60%
Likely Vehicle Mass	<4 Tons	4-24 Tons
Ancillary Loads	Low Power	High Power
Pulsed Power	No	MW-GW
Suspension	Urban/Highway	Unlimited Terrain
Mobility Load	0.3-0.5 Tractive Effort	0.7 Tractive Effort
Emissions	Environmental	Survivability/Signature

**Figure 1. Military Versus Commercial Performance Characteristics**

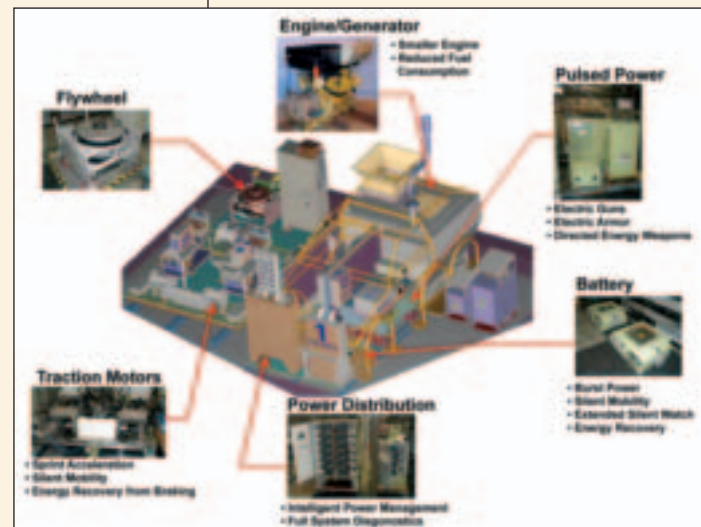
Emerging under the CHPS program, technologies were developed to enable mobile, survivable systems for efficient battle command, mobility, surveillance, targeting and reconnaissance. Warfighters benefit from HE power generation because systems require less fuel, are capable of silent operations and have redundant power systems.

The CHPS' mission was to develop and test a full-scale HEPS for advanced combat vehicles such as FCS. To attain the original goal, the program created under DARPA — with TARDEC collaboration — the hardware-in-the-loop SIL and a sophisticated computational capability for modeling, simulation and virtual prototyping. Additionally, critical component technologies such as lithium-ion batteries, flywheels and silicon carbide switches were brought into the program for further development.

The SIL is a reconfigurable laboratory that poses state-of-the-art hardware and controls to simulate a 15-ton Notional Concept Vehicle (NCV). It provides the relevant environment to functionally evaluate, characterize and completely debug the HEPS. Located in Santa Clara, CA, the SIL is where all the HE power hardware is integrated as a system at the MGCV performance level. Configured in a series architecture format, the SIL assumes that all mobility, armor, weapons, communication and vehicles are driven or supplied electronically. This has been the baseline power configuration for the FCS MGCV.

Figure 2 presents an overview of the SIL to date, noting the superimposed yellow outline of a combat vehicle envelope. Most components would fit into the vehicle outline, but that would not be practical in the SIL where access to all hardware is needed for diagnostics and modifications.

The CHPS virtual prototyping capability encompasses end-to-end models of the SIL, NCV, conventional mechanical and HE Abrams main battle tanks, Bradley Fighting Vehicles (BFVs), armored personnel carriers (APCs) and other vehicles used to




**Figure 2. CHPS SIL Overview (MGV outline)**

benchmark emerging HEPS for FCS. The SIL provides us with hard data to validate the models. In turn, the models present guidance for SIL experiments and allow optimizing power management algorithms very quickly and efficiently. Combined with technology advances in power electronics, energy storage, electromagnetic interference mitigation, control systems, thermal management and pulsed power, the CHPS SIL and virtual prototyping capabilities are producing priceless design and operational data for FCS and other advanced HE-powered combat vehicles.

Under CHPS, software has been developed that permits a user to evaluate a spectrum of design and trade studies that range from component performance and characteristics to complete power systems performance. The SIL offers the validation and the basis of upgrades and enhancements to the valuable software tool.

A CHPS program primary objective is to significantly reduce the complete HEPS's size and weight to enable FCS transportability. Compact power generation is chief in facilitating the integration of a pulsed power system as a subsystem of the overall HE power package. The ultimate goal is to reduce the MGVS HEPS by approximately 50 ft<sup>3</sup>. In the future, we will have to reduce the size an additional 50 ft<sup>3</sup> to fully integrate pulsed power within the HEPS.

This baseline HEPS consists of an engine/alternator sized for average power demand; energy storage and power averaging components (battery modules and flywheel) that provided both continuous and pulsed power, power distribution networks, subsystem controls and power conditioning devices.



Emerging CHPS technologies are being developed to enable mobile, survivable systems for more efficient battle command, maneuverability, surveillance, targeting and reconnaissance. HE power generation will consume less fuel, is capable of silent operations and provides redundant power systems. Here, Soldiers from 1st Battalion, 26th Infantry Regiment, 11D, perform maintenance on their M113 APCs in the motor pool at Forward Observation Base Brassfield-Mora, near Samarra, Iraq. (U.S. Army photo by SPC James Smith, 55th Sig. Co. (Combat Camera).)

Component development of chosen critical HE technologies began in addition to the SIL and virtual prototype

system simulation, analysis and testing previously described. "Work to date consists of advancing the state-of-the-art



energy discharge capacitors and silicon carbide switching,” explained Daniel Herrera, TARDEC Associate Director of P&E.

### Technology Highlights

The CHPS program has had many milestones since its formulation in 1996. The SIL has evolved into a fully capable test laboratory for designing and developing HEPS for advanced military vehicles and it supports all of FCS’s mobility requirements. It has operated for roughly 750 hours and more than 5,000 equivalent road miles. The SIL’s complete HEPS incorporates upgraded components essential for designing and testing HE combat vehicles such as the thermal management system, controls, diagnostics and power regulation equipment. The SIL’s support equipment and subsystems provide emulations of the loads because of the vehicle’s interactions with its environment. Fully operational, the SIL is being used for test and analysis studies for HE vehicles and their components.

Future combat vehicles will be required to demonstrate significant increases in mobility, survivability and lethality while reducing logistics burdens. CHPS began the development of the enabling technologies for mobile, survivable systems for efficient battle command, surveillance, targeting and reconnaissance. The hybrid architecture will allow future combat vehicles to provide sufficient electrical power to support continuous mobility loads while concurrently supporting pulsed power loads such as electromagnetic armor and electric weapons or active protection systems. By exploiting HEPS, it may be possible to achieve lethality and survivability in lightweight combat vehicles equivalent to or better than what is currently available in heavier weight classes.

This architecture also supports improved vehicle mobility, reduced acoustic and thermal signatures and enhanced silent watch capabilities.

**MAJ EDWIN W. LEATHERS JR.** is Team Leader, Mobility Research Group, TARDEC. He has a B.S. in education from Central Michigan University and an M.S. in operational management from the University of Phoenix. Leathers is an Army Acquisition Corps member who is Level II certified in program management.

**EUGENE DANIELSON** is Leader for the Systems Integration/Modeling and Simulation/Test Operations Team for TARDEC’s Mobility Directorate. He has a B.S. in mechanical engineering from the University of Minnesota and an M.S. in mechanical engineering from Rensselaer Polytechnic Institute.

**GEORGE FRAZIER** is Manager for the TARDEC Power and Energy Programs at Science Applications International Corp. He has a B.S. in physics from the University of California-Berkeley. Frazier has more than 30 years experience in power and energy. He has been with the program described in this article since its inception in 1996.

**BYRON WONG** is an electrical engineer for S&T Planning, part of the Mobility Research Group, TARDEC. He has a B.S. in electrical engineering from Wayne State University. Wong is Level II certified in systems planning, research, development and engineering.

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technology in high-power flywheel-generators, high-power density inverters, lithium ion batteries, high-current